Breakthrough UV-LIGA Microfabrication of Sub-mm and THz Circuits

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***Abstract*—The U.S. Naval Research Laboratory has been developing a novel UV-LIGA process to create amplifier circuits from 100 GHz through the THz. A 670 GHz EIK ladder test piece has been successfully fabricated with a 0.004 inch diameter beam tunnel, and demonstrates sub-micron fabrication accuracies. The technique is being extended to showcase capabilities at 850 GHz, and 1.03, 1.35 and 1.50 THz.**

I. Introduction And Background

REACHING toward the THz mark for slow wave vacuum electronics is a daunting task, considering the tremendous difficulties in managing tolerances. NRL is working to demonstrate a UV-LIGA approach that could span the fabrication spectrum from 100 GHz to over 1 THz [1-2]. A Patent-Pending embedded polymer monofilament technique allows the beam tunnels to be created in-situ to arbitrary length and shape [3-4]. This technique is now being showcased in a demonstration 220 GHz serpentine waveguide amplifier tube [5] in a companion paper [6].

II. The Tolerance Challenge

Fig. 1 compares two 670 GHz extended interaction klystron circuits based on the EIK design for the DARPA THz program [7]. An industrial company fabricated a ladder structure by wire electrical discharge machining (WEDM) using a 0.001 inch diameter wire (Fig. 1a). Tiny pilot holes were drilled as required by WEDM. This resulted in elliptical slots rather than square slots, which drastically increases the sensitivity of the resonant frequencies in the ladder to the tolerances. In addition, the sidewalls have a rippled appearance due to vibrations of the EDM wire. The beam tunnel was cut by sinker-EDM after fabrication. Such a two-stage process is extremely risky when alignment is a critical factor, as it is for meandering waveguide circuits. The cavity resonators and tuners to complete the EIK circuits were made in separate copper blocks with the ladder circuit sandwiched in between.

III. NRL Circuit Fabrication

The Patent-Pending UV-LIGA technique allows both the tight-tolerance ladder circuit and the beam tunnel to be fabricated in a single step [3-4]. A polymer monofilament the exact size and shape of the electron beam tunnel is embedded into the photoresist. The filament is substantially transparent to UV, so the photoresist can be activated as if the filament was not present. The resulting quasi-3D structure was electroformed to complete the circuit.

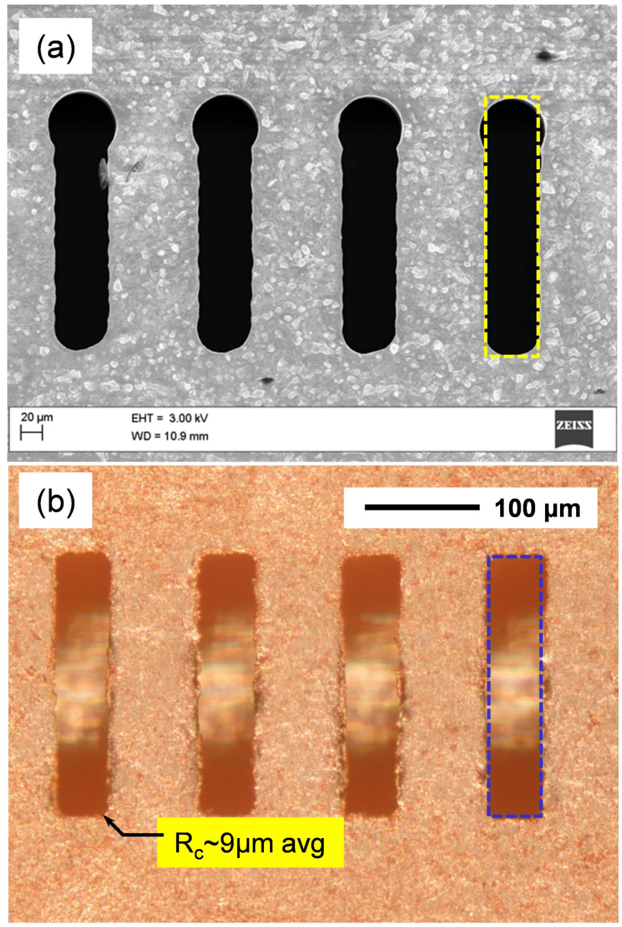

Figure 1. (a) Attempt to make a 670 GHz EIK ladder by industry. There are no corners in the square slots, which are meant to be rectangular; (b) NRL-fabricated ladder using UV-LIGA shows very good corner control. A 0.0040 inch diameter gage pin is seen passing through the beam tunnel.

To simplify the fabrication process for this 670 GHz EIK, the ladder was fabricated on a copper substrate. The filament chosen was a 0.0050 inch diameter ETFE extrusion. Due to the tension needed to ensure the filament was straight, the resulting beam tunnel diameter measures in at approximately 0.004 inch diameter. After SU-8 exposure and electroforming, the wafer is heated to approximately 100°C and the filament is simply pulled to draw it out of the circuit. The SU-8 was removed using a molten salt process [3], which does impart some residual roughness on the copper surface. In spite of the somewhat harsh molten salt treatment, the corner radii, which dominated the geometry in the industrial version, measure in at just 9 µm on average.

TABLE I

Measured Results:			
Std. Dev. [microns]	NRL Best	NRL all	Industry all
Width, W	0.71μm	1.29	2.20
Height, H	0.72	1.08	2.14
Period, P	0.62	0.99	2.14
Depth, D	0.41	1.83	n/a
R_{corner}	0.92	1.33	***None!!***

(Standard deviations in microns.)

Table I is a summary comparing measured statistics of the EDM'd industrial attempt to the NRL UV-LIGA method. The standard deviations of the dimensions are on average almost a factor of two better using the UV-LIGA method. Additionally, the best single EIK section measured in with all standard deviations under 1 μm.

IV. Pushing Fabrication into the THz

To begin to test the limits of the UV-LIGA process, a mask was generated with scaled versions of both EIK ladders and folded waveguide TWT structures at atmospheric window frequencies of 0.85 THz, 1.03 THz, 1.35 THz and 1.5 THz. Since all the structures were on the same mask, the depths of some of the highest frequency structures were significantly deeper than the ideal depth, leading to some issues of poor adhesion and blocked features. With some effort on perfecting the process parameters, the UV-LIGA technique, in conjunction with the embedded filaments, show great promise for extending viable fabrication into the THz.

Fig. 2 shows EIK ladders fabricated from SU-8 at these frequencies. The 1.5 THz version did not adhere well due to excessive vertical aspect ratios greater than 10:1.

Fig. 3 shows the folded waveguide TWT in SU-8 for the same frequency range. The 1.35 THz and 1.5 THz versions were partially blocked due to excessive vertical aspect ratio.

V. Summary

A viable 670 GHz EIK ladder including a beam tunnel has been successfully fabricated using the novel embedded polymer technique. Initial attempts to push the UV-LIGA technique into the THz show promise, extending the applicability of this technique beyond a decade in operating frequencies, from 100 GHz through the 1 THz range.

VI. Acknowledgement

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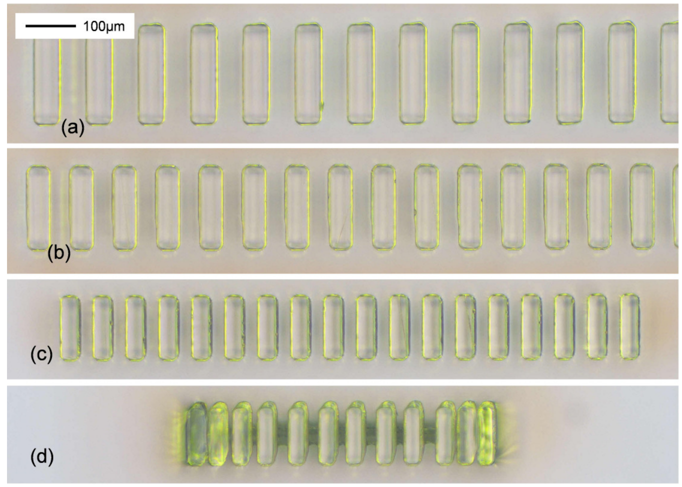

Figure 2. Extended Interaction Klystron ladder molds made from SU-8 at (a) 0.85 THz, (b) 1.03 THz, (c) 1.35 THz and (d) 1.5 THz. The 1.5 THz ladders suffered from poor adhesion due to excessive vertical aspect ratio.

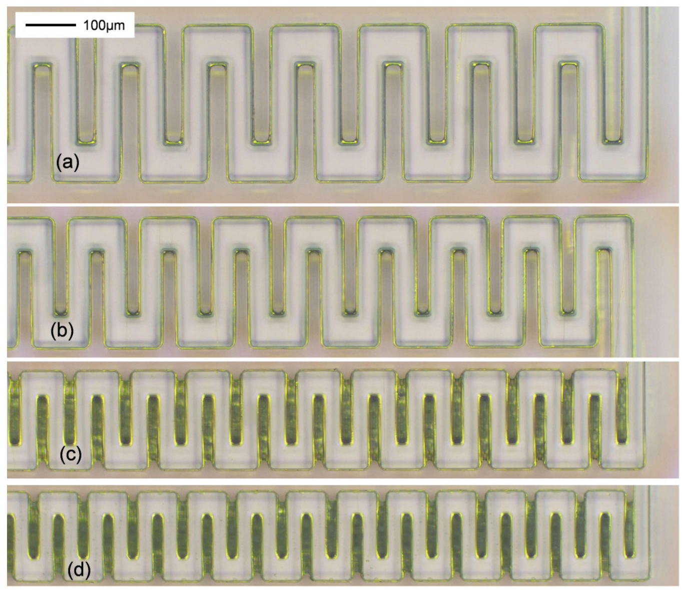

Figure 3. Folded Waveguide TWT circuit molds made from SU-8 at (a) 0.85 THz, (b) 1.03 THz, (c) 1.35 THz and (d) 1.5 THz.

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